He^4 State Equations, 0 K Through the Lambda Line

Vincent Arp [C, S]
Cryodata Inc., Boulder, Colorado, U.S.A.
varp@comcast.net

This paper reports state equations for superfluid He4 valid from 0 K up through the phase boundary T_l to approximately T_l + 0.001 K for all densities from the saturation line to the melting line. The EOS combines (1) temperature-independent compressibility terms, (2) T^4 and higher terms representing phonon excitations dominant below 0.5 K, and (3) energy gap terms representing roton excitations, dominant above 1 K but fading rapidly above $T_{l.}$ From a thermodynamics perspective, the l-line is a line of critical points. The additional range of this EOS, to about Tl+0.001 K, encloses known critical state properties asymptotic to T_l. We report two independent state equations over the above range. One EOS is based on the Gibbs energy G(P,T), plus an ancillary equation $T_l(P)$. The other EOS is based on the Helmholtz energy A(r,T), plus an ancillary equation $T_l(r)$. Published reference data near the l-line implicitly favors the Gibbs EOS, following concepts related to critical theory. In this work we fit each EOS first to all relevant published data. In further tests we compare calculated properties from both EOSs at an array of arbitrary state points. An important parameter this evaluation is the "distance" δT = T - T_l(P *-or-* r) from the l-line. Reference data with |δT| < 10^{-5} K exist only along the saturation line. Two important conclusions are: (1) We find no clear advantage in either a Gibbs or a Helmholtz EOS as judged by goodness of fit to available experimental data. Both equations are more accurate than any predecessor equation. (2) Well known critical expansions of the form A $|\delta T|^{-a}$ $(1 + D|\delta T|^{0.5})$ are inadequate within the EOS. The D-term is not small compared with the first term, for either Gibbs or Helmholtz EOSs, and further expansion in powers of δT is required. Numerical details will be given.

Key words: Gibbs energy, helium-4, Helmholtz energy, lambda line, lambda line asymptotes, Landau equation, phonon, roton, state equation, superfluid